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TYPES OF COMBUSTION CHAMBERS FOR GAS-TURBINE EQUIPMENT

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One of the basic parts of gas-turbine equipment is the combustion chamber. Its purpose is to generate hot gas, the carrier of energy to the turbine. The generation of gas by the combustion chamber takes place as a result of fuel combustion in the compressed air coming from the compressor.

This fuel combustion in the combustion chamber has certain specific features and is subject to a number of unusually rigid requirements, the basic ones being: high specific heat liberation, full completion of the combustion process, uniformity of the temperature field in the gases on the discharge side, as small as possible a pressure loss due to hydraulic resistances, and control and stability of operation over a wide range of calorific power.

These reasons require that special attention be paid to the combustion chamber in solving the whole complex of problems on gas-turbine construction. The present development of combustion chambers, operated on different types of liquid fuel ranging from light kerosene to heavy mazuts, makes it possible to classify them into three types: (1) cylindrical, (2) multitubular, and (3) annular.

Cylindrical Type

The cylindrical combustion chamber is characterized by a single flame space enclosed by a flame tube of considerable diameter which in turn is placed concentrically in a cylindrical casing. The fuel supply into the combustion space is usually fed through a single atomizer, rarely with several. The specific heat liberation attained in cylindrical combustion chambers is $3 \cdot 10^6$ - $5 \cdot 10^6$ large calories per cubic meter per hour (atmospheric pressure) or up to $20 \cdot 10^6$ large calories per cubic meter per hour at a pressure of about 4-4.5 atmospheres and an air temperature at the chamber inlet of up to 400 degrees centigrade. The indicated specific heat liberation levels concern mainly the qualitatively better types of heavy liquid fuels, such as gas oil. Reliable test data on fuels is not yet available.

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Cylindrical combustion chambers have inherently small pressure losses, amounting to 700-800 kilograms per square meter in practice, which corresponds to a loss of 1.5-2.0 percent.

The relatively small pressure losses usually experienced in cylindrical combustion chambers can be explained by the comparatively simple design of this type chamber and by the small air and gas flow velocities in the chamber, in most cases equal to 20-30 meters per second.

Cylindrical combustion chambers are sufficiently perfected as generators of high-temperature compressed gas and can be used for fairly high-powered gas-turbine equipment. The calorific power for chambers of this type attained a level of $30 \cdot 10^6$ large calories per hour with a fuel consumption of 3,000 kilograms per hour and air consumption of 250,000 cubic kilometers per hour [sic]. The dimensions of cylindrical combustion chambers increase correspondingly with an increase in calorific power. Their flame tubes must have a diameter of 800-1,000 millimeters and a length of 2,500-3,000 millimeters.

It should be noted that an increase in the diameter of the cylindrical combustion chamber when the latter is designed for high calorific power presents certain difficulties. With an increase in the diameter of the flame tube, i.e., with an increase in thickness of the combustion chamber's flame space and with an increase in the dimensions and density of the fuel cone, difficulties arise from the mixture of air with fuel and penetration of the air stream into the jet of burning fuel. Similar difficulties bring about a delay in the combustion process in the nucleus of the jet, which is the reason for the latter's prolongation. This, in turn, will necessitate lengthening the flame tube and result in operation of the combustion chamber at a lower specific heat liberation.

To maintain unchanging specific heat liberation levels in the combustion chamber during an increase in its diameter it is necessary to obtain a more intensive injection of the primary air into the flame space, i.e., to introduce it at high velocities. However, this intensification is connected inevitably with an increase in pressure drop within the limits of the combustion chamber, thus making its utilization less desirable.

The above explanation shows that high calorific power in the cylindrical combustion chamber, coupled with an increase in its diameter, leads to either a reduction in specific heat liberation or an increase in pressure drop. All this must be considered in designing this type of combustion chamber for high calorific power. In addition, the increase in the combustion chamber's diameter inevitably involves an increase in the thickness of the casing's walls to assure increased mechanical durability. This especially concerns gas-turbine equipment with high operating pressures of 12-20 atmospheres and above. These difficulties may be avoided by using several parallel cylindrical combustion chambers instead of one.

The combustion chambers of the type being examined can have either an axial air inlet, i.e., along its longitudinal axis, or an angular inlet. The method used is usually determined by the general arrangement of the gas-turbine equipment. The most frequently used is the angular inlet, since it permits a more compact combustion chamber layout and shorter connecting pipe lines. However, from the viewpoint of fuel combustion in the chamber, the axial air inlet would be preferable since it does not upset the uniform distribution of air in the chamber's cross section and, especially important, the symmetry of the primary air flow into the flame space is maintained. It is desirable, therefore, to retain an axial air inlet in the combustion chamber of a gas-turbine installation. In regard to a vertical or horizontal layout of the cylindrical combustion chamber, operating experience has shown that normal operation can be achieved in either position and its selection should be determined only by the installation conditions for the gas turbine. A vertical layout gives the installation a greater compactness and decreases the space required, but it has the disadvantage that a greater number of bends are necessary in the gas-air flow connecting pipe lines, in comparison with the horizontal layout.

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Multitubular Type

The multitubular type of combustion chamber is characterized by a flame space divided into several separate sections, in each of which the combustion process takes place independently. Thus, in effect, the fuel combustion is distributed among several parallel-inserted combustion chambers which have comparatively small calorific power and small dimensions (including the cross-sectional diameter). This type of fuel combustion makes it possible to intensify the combustion process greatly, i.e., to have small-dimensioned chambers which operate with an unusually high specific heat liberation.

The number of separate sections in the chamber may be varied considerably, e.g., with a given outside diameter it is possible to have six, ten or 16 sections. However, as the number of sections in a given outside diameter is increased, the total cross-sectional area of these sections decreases. A chamber composed of four sections would give the maximum practicable cross-sectional area (62.5 percent of the chamber area). The selection of the number of sections is based on the following considerations:

1. Thorough fuel atomization, best achieved with a large number of small-capacity atomizers.
2. More complete mixing of primary air with the atomized fuel -- easier to obtain when the over-all dimensions for both the primary air flow and the cone of the atomized fuel jet are relatively small.
3. More complete penetration of the secondary air introduced into the jet of burning fuel through the flame tube walls -- also easier to attain for smaller diameters.
4. Lower pressure losses during passage of the air-gas flow through the combustion chamber. These losses depend largely on the velocity of flow, i.e., on the cross-sectional dimensions of the sections.
5. Securing favorable conditions for supplying air from the compressor to the sections and gases from the latter to the turbine, as well as assuring that sufficient space is available within the inner tangential circle of the sections for the shaft and other parts of the engine.

As can be seen from the above, some of the considerations involved in selecting the number of sections contradict each other.

The number of sections used in practice varies from six to 16, while the specific heat liberation averages $(60-140) \times 10^6$ large calories per cubic meter per hour with a maximum of around 250×10^6 large calories per cubic meter per hour, or in atmosphere, $(15-30) \times 10^6$ large calories per cubic meter per hour. The indicated values of specific heat liberation refer only to the use of light liquid fuels, mainly to kerosene. Considerable pressure losses, averaging 3 to 8 percent, accompany the high specific heat liberation values characteristic of multitubular combustion chambers. This corresponds to a pressure drop of 1,000-3,000 kilograms per square meter for pressures of around 4 atmospheres. The average calorific power of one section is $(0.6-1.5) \times 10^6$ large calories per hour and up to around 3×10^6 large calories per hour.

The chief advantage of multitubular-type combustion chambers, aside from the possibility of developing high specific heat liberation, is that it is incomparably easier to make final refinements to the combustion chamber on the test stand than in any of the other types. It is sufficient to carry out tests of the full calorific power on only one section, i.e., on one part of the combustion chamber, which greatly simplifies the whole technique of test-stand operation, and decreases the requirements for large facilities, above all, the output required from the compressor station. Since the design and operating characteristics of any combustion

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chamber are determined mainly on the basis of experimental results and not by calculation, then the adaptability of a combustion chamber to test-stand observations assumes major importance.

Annular Type

The third type of combustion chamber, the annular type, has a single flame space in the form of an annular cavity made up of two cylindrical sections concentrically placed. To fill up the annular flame space with the fuel jet, it is necessary to have a large number of atomizers, e.g., 10, 16, or 20. Corresponding to this number of atomizers, the width of the flame space (the distance between concentric cylinders) becomes quite small -- about 150-200 millimeters. This small width is easily penetrated by air, and the atomization of the fuel by a large number of jets of low calorific power facilitates thorough mixture of the fuel with the air and a high degree of atomization, which makes it possible to achieve high specific heat liberation. As a result of this and the magnitude of pressure losses, the annular combustion chamber is comparable to the multitubular chamber.

Advantages of the annular-type combustion chamber over the types mentioned previously are: fuller utilization of the volume available in the engine for the flame space, and greater uniformity in the temperature of gases as they leave the chamber. However, the difficulties in obtaining test-stand data, which can be carried out only by using the whole combustion chamber, rather than a small part of it, and the complexities of their manufacture are the major reasons why annular combustion chambers have not been adopted widely. Selection of a suitable type of combustion chamber depends on various considerations, the most important of which is the over-all scheme and layout of the gas-turbine equipment. In those cases where, due to rigid requirements for minimum dimensions and weight, the gas-turbine installation is designed and constructed as a single-shaft aggregate in which the compressor, combustion chamber, and turbine form a single organic whole structurally, the combustion chamber is either of the multitubular or the annular type and is fitted very compactly between the compressor and the turbine. Its connecting pipe lines are correspondingly reduced to a minimum, and the shaft extends from the turbine to the compressor, passing through the open inner space in the center of the multitubular or annular combustion chamber.

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